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Systemic insecticides for protecting northern spruce and pine seed trees

W.H. Fogal and V.C. Plowman

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Petawawa National Forestry Institute

PETAWAWA NATIONAL FORESTRY INSTITUTE

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SYSTEMIC INSECTICIDES FOR PROTECTING NORTHERN SPRUCE AND PINE SEED TREES

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Abstract

Control of cone and seed insects on white spruce *Picea glauca* (Moench) Voss, black spruce *Picea mariana* (Mill.) B.S.P., red pine *Pinus resinosa* Ait., and eastern white pine *Pinus strobus* L. is possible with systemic insecticides applied to crowns in three ways: with hydraulic sprayers or mist blowers, incorporated into stems by injection or implant, or incorporated into soil in a granular or liquid form. Field trials have been conducted with acephate, carbofuran, dicrotophos, dimethoate, formothion, methomyl, oxydemetonmethyl, and phorate. Dimethoate is registered for use in Canada as a crown hydraulic spray on spruces. Carbofuran is registered in the U.S.A. for northern pines by incorporating granules into soil. While treatments reduce the frequency of insect-damaged cones, they do not always provide increases in seed yield. Insect feeding behaviour, uptake, translocation and metabolism of insecticides, losses of seeds and cones to factors other than insects, and the size of the cone crop are critical factors influencing the efficacy of insecticide treatments.

Résumé

Il est possible de lutter contre les insectes qui nuisent aux cônes et aux graines de l'épinette blanche (*Picea glauca* [Moench] Voss), de l'épinette noire (*Picea mariana* [Mill.] B.S.P.), du pin rouge (*Pinus resinosa* Ait.) et du pin blanc (*Pinus strobus* L.) à l'aide des insecticides systémiques appliqués de trois façons dans le houppier: par pulvérisation à l'aide d'un appareil à pression de liquide ou d'un nébulisateur; par injection ou implantation dans la tige; ou par incorporation dans le sol sous forme granulaire ou liquide. Des essais sur le terrain ont été effectués avec les insecticides suivants: acéphate, carbofuran, dicrotophos, diméthoate, formothion, méthomyl, oxydéméton-méthyle et phorate. Le diméthoate est homologué au Canada pour utilisation sur les épinettes par pulvérisation à pression de liquide. Le carbofuran est homologué aux États-Unis pour utilisation sur les pins du Nord par incorporation de granulés dans le sol. Même si les traitements permettent de réduire la fréquence des dommages causés aux cônes par les insectes, ils n'assurent pas toujours une augmentation du rendement en graines. Le comportement d'alimentation des insectes, l'ingestion, la translocation et le métabolisme des insecticides, les pertes de graines et de cônes dues à des facteurs autres que les insectes ainsi que l'importance de la récolte de cônes sont des facteurs critiques relativement à l'efficacité des traitements insecticides.

The mention of brand names in this report does not imply endorsement by Forestry Canada or its employees. Users of pesticides should consult with local, provincial, and federal health and pest control officials about relevant regulations. Caution should be exercised.

Introduction

Increasingly larger quantities of northern spruce and pine seed are needed by the forestry sectors in Canada and the northern USA for reforestation efforts. Coupled with this is a desire to use genetically improved seed to ensure that new forests are fast-growing, hardy, tolerant of insects and diseases, and produce high-quality wood and fibre. Seed orchards can provide this type of seed. Some orchards have already begun to produce limited quantities of high value, genetically improved seed. The supply of such seed will increase as new orchards now being established come into production (Schooley and Mullin 1987).

Seed orchards require long range programs of tree selection and progeny testing (Matyas and Rauter 1987, Rauter 1985). Large capital investments are needed for initial establishment of such orchards and annual maintenance costs are required over their productive lifetime (Bégin and Crooks 1984, Matyas and Rauter 1987, Morgenstern 1982). Several problems that reduce the productivity of orchards have been identified by seed orchard managers. They include losses of cones and seeds to pests, particularly insects, inadequate flower and cone production in young trees, and inadequate pollination (Konishi 1981, Morgenstern and Carlson 1979). Insects are thought to be a major factor limiting their productivity. Cone- and seed-feeding insects will cause direct losses of cones and seeds, whereas defoliating and sucking insects, as well as bark beetles and borers, can indirectly reduce cone and seed production; they may even cause tree mortality (Dinus and Yates 1975). As well, the supply of healthy scions and seed from plus trees that serve as parental material for orchards will be threatened from time to time by insects. Many species that feed directly on cones and seeds are recognized (Hedlin et al. 1980) and the impact of major insects on cone and seed production in spruce and pine has been outlined (Fogal 1979).

Several systemic insecticides show promise for use against cone and seed insects. In this report we review the trials that have been conducted to find systemic insecticides for control of insects that feed on cones, seeds, and foliage of spruce and pine seed trees. We also discuss several factors that influence the assessment and efficacy of treatments: treatment timing and insect feeding behaviour; uptake, translocation, and metabolism of insecticides; losses of cones and seeds to factors other than insects; and size of the cone crop.

Review of Field Trials

Three modes of insecticide application have been tested. They include spraying crowns, injecting or implanting into stems, and incorporating into soil. Results of the trials are shown in tabular form in Table 1 and discussed below.

1. Crown treatments

Systemic insecticides have been applied to cone-bearing crowns of black and white spruce but not pines. Crowns have been treated by spraying with hydraulic sprayers or mist-blowers from the ground using extension poles, ladders, or lifts to direct the sprays to the tops of trees; helicopters have been used for aerial applications.

(a) Black spruce

(i) Haig and McPhee (1969) applied dimethoate and oxydemetonmethyl to cone-bearing portions of 12 m to 17 m tall trees with a mist blower or backpack hydraulic sprayer. The mists, applied to the point of glistening, contained 2% or 5% AI (active ingredient) providing rates of 9.1 to 22.7 g (grams) AI/tree for dimethoate and 4.5 to 11.4 g AI/tree for oxydemetonmethyl. The hydraulic sprays, applied to drip point, contained 0.1, 0.5, or 1.0% AI to provide rates of 1.1 to 13.6 g AI/tree for dimethoate and 0.6 to 6.8 g AI/tree for oxydemetonmethyl. Trees were treated on June 13 to coincide with flowering, or two weeks later on June 27, 1967.

In the early treatment with the mist blower, both insecticides effectively reduced the frequency of cones attacked by insects, particularly the spruce cone-axis midge *Dasineura rachiphage* Tripp. Dimethoate was most effective, providing 82 to 100% reduction in the number of damaged cones. Oxydemetonmethyl was less effective (39 to 72% reduction in number of damaged cones) but may have been as effective had its rate of application been the same as dimethoate. When applied with the hydraulic sprayer, both

Table 1. Experimental field trials of systemic insecticides for control of insect damage to cones, seeds, and/or foliage of spruce and pine seed trees.

Modes of application, tree species, references, and geographical location	Application technique, insecticide(s), application rates and times	Per cent reduction in defoliation	Per cent reduction in number of damaged cones	Per cent increase in filled seed per cone	Phytotoxicity
1. Crown treatments					
A) Black spruce Haig and McPhee 1969 Longlac, Ont.	*Backpack mist blower* dimethoate (2-5%) 9.1-22.7 g AI/tree June 13, 1967 June 27, 1967	- -	86-100 0-5	- -	- -
	oxydemetonmethyl (2-5%) 4.5-11.4 g AI/tree June 13, 1967 June 27, 1967	- -	39-72 13-39	- -	- -
	dimethoate (5%) 15 g AI/tree June 11, 1968	-	100	-	-
	Backpack hydraulic sprayer dimethoate (0.1-1.0%) 1.1-13.6 g AI/tree June 13, 1967 June 27, 1967	- -	50-100 0-27	- -	- -
	oxydemetonmethyl (0.1-1.0%) 0.6-6.8 g AI/tree June 13, 1967 June 27, 1967	- -	59-100 13-57	- -	- -
	dimethoate (1%) 12 g AI/tree June 11, 1968	-	100	-	-
(ii) Prévost 1986 Sault Ste. Marie, Ont.	*Backpack hydraulic sprayer* dimethoate (0.044%) 3.8 g AI/tree May 10, 1984	-	0-68	-	no increase in flower abortion
B) White spruce (i) Hedlin 1973 Houston, B.C.	*Backpack hydraulic sprayer* dimethoate, (0.5-1.0%) dicrotophos (0.-5-1.0%) oxydemetonmethyl (0.5-1.0%) formothion (0.5-1.0%) June 12 and 13, 1969	- - - -	(88-99)[1] (0)[1] (0-58)[1] (0-98)[1]	0 0 0 0	no effect on seed germination

Table 1. (Cont'd)

Modes of application, tree species, references, and geographical location	Application technique, insecticide(s), application rates and times	Per cent reduction in defoliation	Per cent reduction in number of damaged cones	Per cent increase in filled seed per cone	Phytotoxicity
(ii) Miller and Hutcheson 1981 Everett Creek, B.C.	*Helicopter-mounted hydraulic sprayer* (horizontal boom - individual trees) dimethoate, 0.8% spray 98.4 g AI/tree, June 19, 1979	-	(100)[1]	43	-
Willow River, B.C.	(A-frame boom - individual trees) dimethoate, 0.8% spray 18.0 g AI/tree June 9, 1979	-	(87)[1]	-	-
Evans Creek, B.C.	(horizontal booms - broadcast over many trees) dimethoate, 2% spray, broadcast at 1.67 kg/ha June 21, 1979	-	(68)[1]	22	-
(iii) Fogal and Lopushanski 1985 Chalk River, Ont.	*Backpack hydraulic sprayer* dimethoate, (1.0-1.5) methomyl, (1.0-1.5) acephate (1.0-1.5) 1.3 - 2.5 g AI/cm DBH 4-30 g AI/tree June 1 and 5, 1979	- - -	0-100 0--100 0-95	- -	needle browning evident at the high rate
2. <u>Stem treatments</u> A) Black spruce (i) West 1987 North Pond, Nfld.	*Implants* acephate 0.3 g AI/cm DBH 2.5 g AI/tree Acecaps® June 3-4, 1986	-	72-100	129	no reduction in seed germination
(B) White spruce (i) Fogal and Lopushanski 1989 Pembroke, Ont.	*Injections* dicrotophos 1.1 g AI/cm DBH 28 g AI/tree Mauget® capsules May 22 and 23, 1981	50-100	0-100	90-558	no visible needle browning and no reduction in seed germination

Table 1. (Cont'd)

Modes of application, tree species, references, and geographical location	Application technique, insecticide(s), application rates and times	Per cent reduction in defoliation	Per cent reduction in number of damaged cones	Per cent increase in filled seed per cone	Phytotoxicity
	oxydemetonmethyl 0.7 g AI/cm DBH 19 g AI/tree Mauget® capsules May 22 and 23, 1981	20-68	0-100	115-267	"
Chalk River, Ont.	*Implants* acephate 0.5 and 1.0 g AI/cm DBH 8 and 15 g AI/tree Acecaps® June 1 and 2, 1981	-	0-100	0	"
B) White pine					
(i) Hastings and Avery 1968 Canterbury, NH	*Injections* dicrotophos 3.4 g AI/cm DBH 133 g AI/tree Mauget® capsules May 14 to 17, 1967	-	73	-	-
3. Soil treatments					
A) Black spruce					
(i) Fogal et al. 1988a Kapuskasing, Ont.	*Drill-hoe incorporation* granular carbofuran	0-80	0	0	no needle browning
	Surface spray liquid carbofuran 5 and 10 g AI/cm DBH 49 and 97 g AI/tree May 14, 1980	48-85	0	0-153	some needle browning at 10 g AI/cm DBH in year 2
B) White spruce					
(i) Fogal et al. 1981 Kapuskasing, Ont.	*Broadcast and raked* granular carbofuran 10.8 and 21.6 g AI/cm DBH 95 and 190 g AI/tree May 17, 1979	93 and 100	-	-	none at 10.8 g AI/cm DBH, needle browning and significant increase in number of seed cone buds at 21.6 g AI/cm DBH
Cerezke and Holmes 1986 Grande Prairie, Alta.	*Hand-hoed furrows* granular carbofuran 4.5 to 8.9 g AI/cm DBH May 22-25 and early June 1979	-	0-100	0	up to 26% decrease in filled seeds per cone and 15% decrease in germination

Table 1. (Cont'd)

Modes of application, tree species, references, and geographical location	Application technique, insecticide(s), application rates and times	Per cent reduction in defoliation	Per cent reduction in number of damaged cones	Per cent increase in filled seed per cone	Phytotoxicity
C) Jack pine	*Broadcast*				
(i) Rauf et al. 1982 Oneida Co., WI	granular carbofuran 6.8 g AI/cm DBH May 14, 1982	-	88	–	-
D) White pine	*Broadcast and covered*				
(i) Ehlers et al. 1978 Maumee State Forest, OH	granular carbofuran 8.9 g AI/cm DBH 237 g AI/tree Different treatment times at monthly intervals from November 1977 to April 1978	-	67-91	-	-
(ii) DeBarr et al. 1982 Morgantown, NC	*Broadcast and raked*				
	granular carbofuran	-	54-76	-	-
	phorate granules 65 g AI/tree April 12, 1974	-	16-30	-	-
	granular carbofuran 4.5-13.5 g AI/cm DBH 66-197 g AI/tree				
	March 5, 1975	-	72-97	25-125	-
	March 3, 1976	-	0	-	-
Murphy, NC	*Broadcast and raked*				
	granular carbofuran 4-5.13.5 g AI/cm DBH 40-120 g AI/tree				
	Feb. 23, 1976	-	(67-91)[2]	(190-173)[3]	slight discolouration at apex of current year needles
	Feb. 22, 1977	-	(68-77)[2]	(55-68)[3]	
	Power-till seeder				
	granular carbofuran 4.5 and 9.0 g AI/cm DBH 40-80 g AI/tree	-	45-100	(238-286)[3]	-

Table 1. (Cont'd)

Modes of application, tree species, references, and geographical location	Application technique, insecticide(s), application rates and times	Per cent reduction in defoliation	Per cent reduction in number of damaged cones	Per cent increase in filled seed per cone	Phytotoxicity
E) Red pine (i) Rush et al. 1987 Avoca, WI	*Broadcast* granular carbofuran	-	66	3067	slight yellowing and browning of needles
	Sprinkled liquid carbofuran 8.9 g AI/cm DBH 138 g AI/tree May 17, 1984	-	88	4400	very noticeable yellowing and browning of needles

[1]Per cent reduction in number of larvae per cone.
[2]Per cent reduction in number of damaged seed.
[3]Increase in number of seeds per cone.

insecticides provided good to excellent reduction in frequency of cones damaged by insects. Oxydemetonmethyl provided 59 to 100% reduction of damaged cones and dimethoate provided 50 to 100% reduction.

Treatments at the later date were less effective. Mists of oxydemetonmethyl provided 13 to 33% and dimethoate 0 to 5% reductions in cone infestation; for the sprays, reductions were 13 to 57% for oxydemetonmethyl and 0 to 27% for dimethoate. Oxydemetonmethyl was thus more effective than dimethoate at the later treatment time.

For the mists, better control was achieved with the 5% AI than the 2% AI. For the sprays, 0.5% AI was usually better or equal to the 0.1% or 1.0% AI.

In 1968, trees approximately 4 m in height were treated on June 11 with mists containing 5% AI dimethoate (15 g AI/tree) or with spray containing 1% AI dimethoate (12 g AI/tree). These treatments provided 100% reductions in cone damage.

(ii) Prevost (1986) sprayed the upper half of black spruce crowns with a backpack hydraulic sprayer to the point of runoff with 0.044% AI of dimethoate on May 10, 1984. At this time, about two weeks before flowers opened for pollination, seed cone buds were swollen. Trees averages 12 m in height and were about 30 years old. Each tree received approximately 3.8 g AI of insecticide.

The treatment provided excellent control of damage to seed cone buds and cones (68% reduction in number of damaged cones) by lepidoptera larvae, primarily budworm *Choristoneura fumiferana* (Clem), and coneworm *Dioryctria reniculelloides* Mutuura and Munro. However, damage by the cone maggot *Lasiomma anthracina* (Czerny) and the cone-axis midge was not reduced, perhaps because of the low concentration of insecticide in the spray or because treatments were applied too early. Treatments did not cause increases in abortion of conelets.

(b) <u>White spruce</u>

(i) Hedlin (1973) sprayed cone-bearing portions of 6 m to 12 m tall trees with 0.5 to 1.0% AI of dimethoate, dicrotophos, oxydemetonmethyl, or formothion applied to runoff using a backpack hydraulic sprayer on June 12 and 13, 1969. Some conelets were still in the erect position with open scales, but most were closed and horizontal.

Significant levels of mortality of spruce seedmoth *Cydia strobilella* (L.) and cone maggot were achieved with dimethoate (88 to 99% reduction in numbers of larvae per cone). Formothion provided 0 to 98% reduction and oxydemetonmethyl, 0 to 58%; dicrotophos was ineffective. There was no increase in number of filled seeds per cone, but none of the insecticides had any deleterious effect on seed germination.

(ii) Miller and Hutcheson (1982) used a helicopter-mounted horizontal boom to spray upper crowns of 27 to 33 m tall trees with 0.8% AI of dimethoate; each tree received about 98 g AI, and treatments were applied June 19, 1979. At the time of treatment, conelets were closed and in the pendant position or turning to the pendant position. Excellent control of cone maggot (100% reduction in numbers of larvae per cone) and 43% increases in seed yield were achieved. When an A-frame boom was used to direct spray to the crowns, the amount of insecticide required to provide control (87% reduction in numbers of larvae per cone) was reduced to 18 g AI/tree.

Broadcast applications of 2% dimethoate at a rate of 83.46L/ha (1.67 kg/ha) on June 21, 1979 also provided excellent cone maggot mortality (68% reduction in numbers of larvae per cone) and significantly increased the number of filled seeds per cone (22%).

(iii) Fogal and Lopushanski (1985) applied hydraulic sprays of dimethoate, methomyl, and acephate containing 1.0 and 1.5% AI to trees in 12-year-old and 25-year-old white spruce plantations. The 12-year-old trees received 1.3 and 1.9 g AI/cm DBH (6 and 9 g AI/tree) and the 25-year-old trees received 1.6 and 2.5 g AI/cm DBH (20 and 31 g AI/tree). Cone-bearing portions of 4 to 7 meter tall trees were sprayed to the drip point with a backpack sprayer on June 1, 1979 in the 12-year-old plantation and June 5, 1979 in the 25-year-old plantation approximately three weeks after peak flowering.

Cone damage was reduced by insecticides but no differences between the two application rates

were detected. In the younger plantation, each insecticide provided highly significant reductions in cone damage by spruce coneworm (80 to 95% reductions), spruce cone maggot (67 to 80%), and spruce cone-axis midge (64 to 100%), but none reduced spruce budworm damage. There appeared to be little difference in efficacy among the insecticides tested. In the older plantation, each insecticide gave significant reductions in cone maggot damage (45 to 72%) with no statistically significant differences among them. Dimethoate and methomyl, but not acephate, reduced damage by seedmoth and cone-axis midge. None of the insecticides reduced coneworm damage. Treatments appeared to be less effective in the older plantation.

Some phytotoxicity, evident as needle browning, was noted when higher concentrations were used.

2. Stem treatments

Implants of solid formulation of insecticide by means of Acecap® units and injection of liquid formulations using Mauget® injectors have been conducted on black spruce, white spruce, and white pine.

(a) Black spruce

(i) West (1987) implanted trees approximately 5 m in height with solid acephate by means of Acecap® capsules at a rate of 0.3 g AI/cm DBH (2.6 g AI/tree) on 3 to 4 June, 1986, shortly after pollination.

Treatments provided 72% reduction in cone damage by insects that feed externally on cones, including the coneworm and budworm, and 100% reduction by internal feeders such as the cone maggot and cone axis midge. Extractable seed yields were increased 129%, with no apparent reduction in seed germinability.

(b) White spruce

(i) Fogal and Lopushanski (1989) injected trees approximately 18 m in height with a liquid dicrotophos formulation at 1.1 g AI/cm DBH (28 g AI/tree) and a liquid oxydemetonmethyl formulation at 0.7 g AI/cm DBH (19 g AI/tree) by means of Mauget® injectors on May 22 and 23, 1981, four days after the peak of pollination.

Defoliation by budworm was reduced at upper, middle, and lower crown levels for two seasons following injection. This suggests that the insecticides were persistent and equally effective at all crown levels, and it implies that seed cones on the upper crown and pollen cones on the lower crown should be protected. Dicrotophos was more effective than oxydemetonmethyl.

In the treatment year, injections reduced the proportions of cones damaged by insects that feed exclusively in cones and initiate feeding after pollination (seedmoth, cone maggot, cone-axis midge, and seed inhabitants such as the spruce seed midge *Mayetiola carpophage* (Tripp) and/or seed chalcid *Megastigmus atedius* Walker) by 94 to 100%. Damage by insects that initiate feeding on cones and foliage before or during pollination (budworm and coneworm) was not reduced. Seeds per cone were increased 558% by dicrotophos and 267% by oxydemetonmethyl.

In the season after injection, the proportion of cones damaged by budworm was reduced 100% by dicrotophos and 89% by oxydemetonmethyl. Seed-inhabitant damage was reduced 89% by dicrotophos whereas oxydemetonmethyl was ineffective; damage by other insects was not reduced by either insecticide. Nonetheless, the number of seeds was increased by 90% with dicrotophos and by 115% with oxydemetonmethyl.

Treatments did not cause any visible signs of phytotoxic stress by comparison with untreated trees and wounds caused by injections healed well (Bowen 1987).

(ii) Fogal and Lopushanski (1989) implanted a solid formulation of acephate by means of Acecap® capsules into 9.4 m trees on June 1 and 2, 1981, approximately two weeks after peak flowering and pollination for control of cone and seed damage at rates of 0.5 and 1.0 g AI/cm DBH (8 and 15 g AI/tree).

In the year of treatment, most of the cones on trees treated at a rate of 0.5 g AI/cm DBH were lost to red squirrels *Tamiasciurus hudsonicus*, so no assessment of treatment effect on insect damage and seed yields could be made. Fewer cones were lost to squirrels on trees treated with 1.0 g AI/cm DBH and seed moth damage to those remaining on the trees was reduced by

100% compared to untreated trees. Cone damage by other insects was not reduced by the treatment and no increase in seed counts was evident.

In the season after implanting, squirrels were not a noticeable problem, perhaps because the cone crop was much larger and they had a more abundant food supply. The treatments provided excellent reductions in cone damage by insects: coneworm damage was reduced 100% by both insecticide rates; seed moth by 70 and 50% respectively for the 0.5 and 1.0 g rates; cone maggot by 65 and 91%; and seed inhabitants by 92% for both rates. Despite insect control, the number of seeds per cone was not increased.

(c) White pine

(i) Hastings and Avery (1968) injected dicrotophos into white pine trees 17 m in height at a rate of 3.4 g AI/cm DBH (133 g AI/tree) on May 4-17, 1967. Treatments provided 73% reduction in cone damage by the white pine cone beetle *Conophthorus coniperda* (Schwarz). Seed yields were not determined.

3. Soil treatments

Granular formulations are incorporated into soil or litter to prevent birds feeding on pellets. They are incorporated in two ways: hand broadcasting, followed by raking into duff or covering granules with litter or shavings; inserting into furrows hoed by hand, by motor-powered hoe drill, or disc furrower. Liquid formulations have been applied by hand sprinkling or by motorized sprayer.

(a) Black spruce

(i) Fogal et al. (1988a, b) treated 29-year-old trees averaging 9.7 cm DBH with 5 or 10 g AI/cm DBH (49 or 97 g AI/tree) carbofuran as a granular or liquid formulation on May 14, 1980, well before pollination. Granules were incorporated into soil with a hoe-drill applicator and the liquid was sprayed onto the surface.

Treatments with liquid carbofuran effectively prevented defoliation by spruce budworm in the year of treatment and persisted the year after treatment. Granular carbofuran was not effective in the year of treatment, perhaps because of low rainfall after treatments; it was effective the following year. Treatments were effective at upper, middle, and lower crown positions. They had no detectable influence on cone yields or cone damage by insects in either year of assessment; however, cone seed counts were increased 153% by the liquid formulation at 5 g AI/cm DBH in the year after treatment. Phytotoxic stress was evident at the 10 g AI/cm DBH liquid formulation in the second year of assessment, but not at 5 g AI/cm DBH or either rate of the granular formulation.

This trial was done under less than optimum conditions for evaluating effects on cone production and seed yields because the cone crops were very poor in both years of assessment.

(b) White spruce

(i) Fogal et al. (1981) treated 17-year-old trees averaging 8.8 cm DBH with granular carbofuran by broadcasting and raking granules into litter and upper soil layers. The insecticide was applied 17 May, well before pollination, at rates of 10.8 and 21.6 g AI/cm DBH (95 and 190 g AI/tree). Shortly after the treatment, substantial quantities of rain fell.

Both dosages provided excellent foliage protection from spruce budworm. At the higher rate phytotoxic stress showed up as needle browning but there appeared no visible sign of such stress at the lower rate. Seed cone bud production was enhanced significantly on trees given the higher rate. It is not known, however, whether this increase in seed-cone bud production was related to protection of foliage from budworm feeding or to a stimulatory effect on flowering.

(ii) Cerezke and Holmes (1986) placed granular carbofuran in small furrows scraped to the mineral soil and then covered them with litter. Application rates ranged from 4.5 to 8.9 g AI/cm DBH in trees ranging from 20-25 m in height. Treatments were applied when terminal buds were beginning to swell, between May 22-25, 1979, at one site and at a second site when conelets had just flushed and were in the upright position during the first week of June.

Eight insect species were found associated with the cones and treatments provided 0 to 100% reductions in proportions of cones damaged.

Significant reductions were observed for cone maggot, spruce seed midge, cone-axis midge, and cone-gall midge *Dasineura canadensis* Felt. Overall reduction for all insects and treatments was 55% at the site treated in June and 18% at the site treated in May.

Treatments did not promote increases in the number of filled seeds per cone. The cone crop was reported to be very heavy, insect infestation rates were low, and overall seed losses to insects were very light (1 to 6%).

A phytotoxic effect of treatments was suggested by reductions in cone length, seed yield, and seed germination.

(c) Jack pine

(i) Rauf et al. (1982) treated 9-year-old jack pine trees with granular carbofuran to control conelet abortion caused by the pine conelet bug *Platylgus luridus* (Reuter). Granules were broadcast onto the soil surface on May 14, 1982 at a rate of 6.8 g AI/cm DBH.

During the months of July, August, and September adults of the pine conelet bug were found on untreated trees but not on treated trees. By October, treatments had provided an 88% reduction in conelet abortion.

(d) White pine

(i) Ehlers et al. (1978) broadcasted granules in plots delineated by the drip line of trees averaging 26.7 cm DBH. Mineral soil was exposed within the plots by removing litter before treatments. Following treatments, litter and pine peelings were returned to the plots to prevent hazards to wildlife. The insecticide was applied at a rate of 8.9 g AI/cm DBH (237 g AI/tree). Treatments placed at monthly intervals from November to April were compared with untreated trees.

Cone damage by the white pine cone beetle was reduced by 67 to 91%. Treatments in November, December, and January gave better results than those in March and April.

(ii) DeBarr et al. (1982) compared granular carbofuran and phorate at a rate of 4.5 g AI/cm DBH (65 g AI/tree) on 12 April 1974 by broadcasting evenly within an area delineated by the drip line of each tree crown. Grass was mowed prior to treatment and granules raked into the grass to minimize hazard to birds and small mammals.

Cone damage by white pine cone beetle, assessed for two years following treatments, was reduced by 75% in 1974 and 54% in 1975 by carbofuran; phorate was less effective, providing 30 and 16% reductions in 1974 and 1975, respectively.

More extensive trials with carbofuran at 4.5 to 13.5 g AI/cm DBH (66 to 190 g AI/tree) provided 73 to 97% reduction in cone beetle damage but no reductions in frequency of seedbug *Tetyra bipunctata* (Herrich-Schäffer) damage; only the highest rate provided increased seeds per cone. Repeated treatments on the same plots in 1976 and 1977 provided significant increases in filled seed. Depending on treatment, increases over controls ranged from 109 to 173 seed per cone in 1976 and 55 to 68 in 1977. This was accompanied by a significant reduction in seed bug-damaged seed, ranging from 69 to 91% in 1976 and 68 to 77% in 1977. It is worth noting that the smaller increases in filled seed for 1977 were associated with a large cone crop, which was twice the size of the 1976 crop.

Some discoloration of current year needles appeared to be clonal in nature. Phytotoxic symptoms and possible effects on germination were not assessed in detail.

Operational treatments were carried out in 1978 using a John Deere Power Till seeder to incorporate carbofuran granules. This trial provided increases of 238 and 286 in number of filled seeds per cone with rates of 4.5 and 9.0 g AI/cm DBH, respectively. Significant reductions in damage by white pine cone borer *Eucosma tocullionana* Heinrich and white pine cone beetle were reported. Protected trees produced significantly more sound conelets and cones.

(e) Red pine

(i) Rush et al. (1987) compared liquid and granular formulations of carbofuran in large plots containing approximately 25 cone-bearing trees. Granules were applied by hand with a

shaker can, and liquid with a sprinkler can, at a rate of 8.9 g AI/cm DBH (138 g AI/tree).

The liquid formulation provided 88% reduction in the number of insect-damaged cones, and the granules reduced cone damage by 66%. Treatments controlled the eastern pine seedworm *Cydia toreuta* (Grote), the red pine coneworm *Eucosma monitorana* Heinrich, webbing coneworm *Dioryctria disclusa* Heinrich, and a cone resin midge, *Asynapta hopkinsi* Felt.

Increases in numbers of filled seeds per cone amounted to 31-fold for the granules and 44-fold for the liquid formulations; however, some yellowing and browning of needles was observed, particularly for trees treated with the liquid formulation.

The efficacy of insecticides

There is little doubt that insects play a significant role in seed losses (Dinus and Yates 1975) and also that systemic insecticides can control insects and reduce evidence of damage to cones. Nonetheless, treatments do not always provide increases in seed yield nor do they always control insects. Effective insect control depends on the timing of treatments, insect feeding behaviour, and insecticide uptake, translocation, and metabolism. In addition, seed yields are influence by other factors that interfere with the ability of insecticide treatments to improve seed yields. They include losses of seeds and cones to agents other than insects and the size of the cone crop.

1. Timing of treatments and insect feeding behaviour

The timing of insecticide treatments for control of cone and seed insects depends on the insects to be controlled, the tree species that need protection, and the mode of application.

Crown sprays of systemic insecticides on spruces have usually been applied after pollination is over and just before seed cones become pendant. Such treatments control insects that oviposit and initiate feeding after pollination (Fogal and Lopushanski 1985, Haig and McPhee 1969, Hedlin 1973, Miller and Hutcheson 1982). But such treatments do not provide complete control of insects that initiate feeding before pollination, such as the coneworm and spruce budworm (Fogal and Lopushanski 1985). To prevent damage by such species, treatments before flowering and pollination appear to work (Prevost 1986). However, crown sprays should not coincide with flowering lest they interfere with pollination and subsequent fertilization (Annila 1973).

In white spruce, injections of dicrotophos and oxydemetonmethyl after pollination prevented damage by insects that fed exclusively within cones, but they did not protect cones from damage by insects that fed on flowers prior to pollination. In the year following treatments damage by the latter insects was prevented by the residual toxicity of the insecticides. Implants of crystalline acephate were not effective for either type of insect in the year of treatment but, the year after, damage by both types of insect was reduced (Fogal and Lopushanski 1987). Thus, in white spruce, most injections and implants should be carried out as early as possible. For the season under consideration, this might be before flowering, early in the spring. However, in black spruce, treatments can apparently be done after pollination, because implants of crystalline acephate were effective for controlling cone damage by insects that fed before or after pollination (West 1986). Injection of white pine with dicrotophos prior to flowering provided excellent control of white pine cone beetle (Hastings and Avery 1968).

Carbofuran has been used almost exclusively in trials of soil-incorporated insecticide except for one case where phorate was used on white pine. Insecticide is usually applied to soil in early to mid-spring. Results with spring applications can be spectacular (Rush et al. 1987). However, this may not be the optimum time; in white pine, better control of white pine cone beetle was achieved with a fall application of carbofuran (Ehlers et al. 1978).

2. Insecticide uptake, translocation, and metabolism

Mode of application and insecticide formulation influence efficacy. For example, hydraulic sprays of dicrotophos were ineffective on white spruce (Hedlin 1973), whereas injected dicrotophos was very effective (Fogal and Lopushanski 1989). Liquid formulations of carbofuran are apparent-

ly taken up by the trees more rapidly than granular formulations and are thus more effective in the year of treatment (Fogal et al. 1988a, Rush and Overton 1987). Timely rainfall may improve the effectiveness of granular formulations in the year of treatment (Fogal et al. 1981).

Systemic insecticides commonly display residual activity for more than one year in trees (Norris and Coppel 1961, Al-Azawa and Norris 1959, Pree and Saunders 1973, 1974). Such persistent and long-term residual activity suggests that metabolism of insecticides is relatively slow in trees. This allows considerable flexibility in timing of treatments because they can be applied in advance of anticipated outbreaks or feeding periods and retain sufficient activity to protect the crop.

Fogal and Lopushanski (1985) found that control of insects with foliar-applied insecticides was lower in a 25-year-old plantation compared to a 12-year-old, in spite of the fact that older trees received more insecticide per unit of stem diameter as well as per tree. An obvious factor that may account for the difference is the amount of insecticide taken up by the tree in relation to tree size. If insecticides were translocated throughout the tree from their point of application on the upper crown, a dilution effect might be expected with increase in diameter, because the biomass of white spruce increases exponentially with increase in tree diameter (Alemdag 1982). Such a dilution effect might explain the lower efficacy in older trees. But age-related biochemical changes in the metabolism and/or translocation of toxicants in the tree should also be considered.

3. Seed losses to other causes

Filled seeds develop from a central fertilized zone in conifer cones (Tripp and Hedlin 1956). In spruces 7% may be lost as a result of ovule abortion before fertilization and approximately 13 to 25% abort at the time of proembryo development (Sarvas 1968, Owens and Molder 1979, Owens and Blake 1985). Embryo abortion is common (Mergen et al. 1965) and may occur in 50 to 75% of potential seeds (Owens and Molder 1979). In pines, 50 to 60% of ovules abort in the fertile region of cones (Lyons 1956, Owens and Blake 1985). Lack of pollen, self pollination, sublethal or defective genes, extreme climatic conditions, competition for nutrients, and internal factors that control development are the most important causes of seed abortion.

Seed losses to causes other than insects will influence the efficacy of insecticide treatments. If large proportions of potential seeds are lost to factors other than insects, expected increases in yield from insecticide treatments will not materialize. Experiments aimed at demonstrating the efficacy of insecticides that reduce insect-caused losses must, therefore, take account of these other losses to ensure that conclusions from insecticide trials are valid. Ideally, the other losses should be controlled too. Finally, the incorporation of systemic insecticides may have direct effects on seed quality but, apart from a report on carbofuran applied to white spruce (Cerezke and Holmes 1986), there is no evidence in the literature to suggest this. This possibility needs to be carefully assessed.

4. Cone losses

Cones like seeds may abort or be lost before seeds are fully mature. Premature cone abscission occurs, but little is known about the cause of this phenomenon either in early or late stages of cone development. One exception is cone drop in pines, which results from inadequate pollination (Dickman and Kozlowski 1973, Sweet 1973). Other factors thought to be responsible include low temperature, moisture stress, inadequate nutrition, and competition between vegetative and reproductive structures (Owens and Blake 1985). It is possible that insect feeding may also cause premature cone abscission (Fogal 1988). Losses of insect-damaged cones, if substantial, might produce an apparent increase of seed yield in remaining cones. Differences in yield between cones from untreated trees and those from treated trees would then be reduced or be undetectable.

Red squirrels harvest large numbers of cones from spruces (Heinselman 1957) and pines (Hurley et al. 1987). Cecich and Rudolph (1982) had difficulty collecting jack pine cones after squirrels began harvesting and Fogal and Lopushanski (1984) reported a similar problem with white spruce. In the latter case, squirrels were a meddlesome nuisance in trials set up to test the efficacy of stem-injected systemic insecticides because sufficient numbers of cones could

not be collected from all experimental trees. In a study on black spruce, Prevost (1986) found that red squirreis were second in importance to lepidopteran insects in accounting for cone and seed losses.

Squirrels are known to avoid cones with obvious damage due to insects (Smith 1981) and feed on trees with high proportions of undamaged cones. Insect-free cones from insecticide-treated white spruce trees appeared to be preferentially harvested (Fogal and Lopushanski 1984). Such differential harvesting by squirrels would influence results of trials by reducing differences in seed yield between insecticide-treated and untreated trees.

5. Cone crop size

Seed yields and damage to cones are influenced by variations in crop size. In spruces, insect damage is usually high and seed yields low in poor crop years, whereas the reverse occurs in good crop years (Werner 1964). Similar correlations between crop size and insect damage occur in pines (Lester 1963, Mattson 1971, Shea et al. 1984). Can variation in crop size influence efficacy of insecticide treatments? To answer this question, consider three hypothetical crops, one good, another moderate, and the third poor.

In a good crop year, only a small proportion of cones will likely be attacked and seed set is likely to be high. Under these conditions, effect of treatments on proportion of cones damaged may be difficult to detect and increases in seed yield from treated trees may be very small. This may have been responsible for the poor results reported by Cerezke and Holmes (1986) for treatment of white spruce trees with carbofuran. The cone crop was reported to be very heavy; overall seed losses to insects were very light and treatments provided essentially no increase in seed yields.

In a moderate crop year, insect damage might be moderate to high and adequate pollination would ensure good seed set. Under such conditions treatments are more likely to provide detectable increases in seed yield. Fogal and Lopushanski (1987) reported substantial increases in seed yield from cones of white spruce trees injected with dicrotophos and oxydemetonmethyl in moderate crop years.

In poor years, high percentages of cones would likely be attacked by insects, but seed set is expected to be low because of poor pollination and selfing; treatments would provide a high degree of protection from insects, with little or no increase in seed yield. Fogal et al. (1987) reported such a lack of effect on seed yields in trials of carbofuran conducted on black spruce trees in years of very poor cone crops. Cone crop size appears to be an important factor to consider during years when insecticide trials are evaluated because it is likely to influence the magnitude of differences in seed yield between treated and untreated trees. For operational purposes Shea et al. (1984) have suggested that size of the cone crop is important, along with size of the insect population and demand for seed, in deciding whether insecticide control is required.

Summary and Conclusions

In spite of the known destructive capabilities of cone and seed- feeding insects on spruce and pine and the high value of seed, only two systemic insecticides are presently registered for use. In Canada, dimethoate has been registered as a crown spray on spruce (Fogal and Lopushanski 1985) and, in the USA, granular carbofuran has been registered for use as a soil additive on northern pine (Rush and Overton 1988). Several other systemic insecticides appear to be excellent candidates, but more effort is required to obtain their registration for commercial use in the treatment of pine and spruce seed trees.

Cone-bearing crowns of black spruce and white spruce, but not pines, have been treated by spraying with hydraulic sprayers or mistblowers from the ground using extension poles, ladders, or hydraulic lifts to direct the sprays to the tops of trees; helicopters have been used for aerial applications. Several insecticides have been tested in spray form including acephate, dicrotophos, dimethoate, formothion, methomyl, and oxydemetonmethyl. The concentration of active ingredient has ranged from 0.044% to 2% for sprays and 2% to 5% for mistblower application. Optimum concentrations have not yet been determined but, for sprays of crowns to the drip point, 0.1 to 1.0% concentration appear to provide good control; phytotoxicity of needles may become apparent above a 1.0% concentration.

Implants of solid formulations and injections of liquid formulations have been conducted on black spruce, white spruce, and white pine. Solid acephate was primarily used in implants, and liquid dicrotophos and oxydemetonmethyl employed in injections of spruces and pines. Rates of application have ranged from 0.3 to 3.4 g AI/cm DBH. Good control has been achieved at all rates with no reports of significant phytotoxicity in terms of needle browning.

Insecticides have been incorporated into soil in trials conducted on black spruce, white spruce, white pine, and red pine. Granular formulations have been applied to soil by hand broadcasting, followed by raking into duff or covering granules with litter or shavings to reduce the chances of birds feeding on pellets. Granules have also been incorporated into furrows hoed by hand, by motor-powered hoe drill, or a disc furrower. Liquid formulations have been applied by hand sprinkling or by motorized sprayer. Trials of soil-applied insecticide have employed carbofuran almost exclusively except for one small trial of phorate. Application rates have ranged from 4.5 to 21.6 AI/cm DBH. Carbofuran treatments have proven to be effective for control of cone and seed insects in pines and spruces but phytotoxic symptoms have been reported with high rates. Liquid formulations appear to be taken up more quickly than granular formulations and are more effective, but phytotoxic symptoms are more severe with liquid formulations compared to granular formulations at the same rate. On the other hand, minimum effective rates might be lower with a liquid formulation.

Timing of treatment is a critical factor affecting the efficacy of treatments and varies with insects to be controlled and mode of application. Other factors that alter the efficacy of treatments include seed and cone losses to agents other than insects, and the size of the cone crops. In future trials, these factors need to be considered and more emphasis must be placed on evaluating seed yields and possible adverse effects of insecticides on cone and seed development and seed germination. In addition, any phytotoxic effects of treatments at application sites or on overall growth and development need to be examined. This is required to ensure that short- or long-term adverse effects of treatments on high value seed trees are minimized and that any deleterious effects of treatments are more than offset by increases in seed productivity.

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